THE HIGH PERFORMANCE MAGAZINE CONCEPT

by

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BACKGROUND

A new storage magazine is needed by the Navy to solve munitions storage problems. Existing magazines encumber large land areas to meet explosives safety quantity distance (ESQD) requirements. A growing inventory of weapons (requiring new magazine construction), with limited land for new explosive storage magazines, is creating conflicts between safety requirements, operational requirements, MILCON cost, and operating cost to store and retrieve weapons.

NCEL is investigating the feasibility of a new magazine that would reduce the land area encumbered by ESQD arcs and improve the efficiency of weapons handling operations. This new High Performance Magazine (HP Magazine) concept could reduce encumbered land by 80% (or increase storage density on existing land by a factor of up to 8 times) and significantly reduce operational costs. Reduction of encumbered land is achieved by reducing the Maximum Credible Event (MCE) in the magazine to around 10,000 lbs Net Explosive Weight (NEW) of High Explosive (HE) by using cells with walls that prevent sympathetic detonation (SD). The magazine would be designed to store about 250,000 lbs NEW of palletized ordnance (e.g. bombs, bullets, projectiles, torpedoes) or about 60,000 lbs of containerized missiles. However the ESQD arcs would be based on an MCE of only about 10,000 lbs (the NEW in one cell). Soil cover will also be used to reduce fragment and debris safe scaled distances.

The HP Magazine development will include three phases. Phase I will determine the feasibility of the wall and roof concepts using existing data bases, analytical procedures, and scale model tests. Phase II will use analytical methods and tests (scale model and one prototype) to develop the final design criteria and to demonstrate the magazine concept for explosives safety. Phase III will use full scale operational tests and one full scale explosive test to certify the operational and explosive safety characteristics of the integrated prototype design.

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CONCEPT

The High Performance (HP) Magazine concept consists of an earth covered box structure with interior cells where munitions are stored, as shown in Figures 1 through 5. The cell walls are designed to prevent sympathetic detonation between cells thereby limiting the MCE to the NEW stored in any cell. The reinforced concrete box structure and soil cover are designed to limit the safe distance for the MCE from blast, fragments, and debris outside the magazine. Containment by the roof and soil cover forces most of the blast overpressure from the MCE to vent through the door openings before the roof is breached. Consequently, the blast environment outside the magazine is equivalent to that from a tunnel magazine, which results in a major reduction in encumbered land to provide safe distances from overpressure outside the magazine. The roof and soil cover mass also serve to limit the maximum launch velocity of debris, thereby limiting the maximum possible strike range of debris. Weapon fragments are stopped (or slowed to safe velocities) by the reinforced concrete box structure and soil cover before the roof is breached.

Design

The conceptual design for an HP magazine is based on preliminary information on the current and projected inventory of munitions and the existing technology base on explosion effects. The concept consists of a box structure, storage cells, earth blanket and material handling system. The conceptual design for each component of the facility is as follows:

Box Structure. The box structure is a reinforced concrete box about 40 feet wide, 200 feet long, and 15 feet from floor to ceiling, as shown in Figures 1, 2, and 3. The box has no interior columns. Access to the box is through a short tunnel located at either one end of the box (Type A HP magazine) or both ends of the box (Type B HP magazine), as shown in Figure 3. In both the Type A and B HP magazines, each door opening is about 12 feet wide by 11 feet high.

Storage Cells. The storage cells may be arranged as shown in either Figure 4a or 4b, depending on the final details of the material handling system and results of a hazards analysis of handling operations. The storage cells are either about 30 to 60 feet long x 12 feet wide x 8 feet high to accommodate air-, surface-, and subsurface-launched missiles (Figures 5a and 5b) or about 16 x 12 x 8 feet to accommodate pallets of bombs, bullets, projectiles, mines and torpedoes (Figure 5c).

The cell walls are modular and movable to accommodate shifting demands in the cell size needed to store different types of ordnance. Wall materials, yet to be defined, will be chosen to mitigate the mechanisms that would cause sympathetic detonation in the adjacent acceptor cells.

Corridors are provided for access to storage in any cell. The number corridors depends on the arrangement of storage cells, as illustrated in Figure 4. In all cases, the corridors are about 8 feet wide.

Soil Cover. The box structure is covered with soil (about 5 feet deep), as shown in Figure 1. Fabric-reinforced soil cover may be used to increase the mass of soil mobilized when the roof fails. Increasing the mass of the failed roof section reduces the launch velocity of debris and the safe debris distance.

Storage Capacity

The storage capacity of the Type A and B HP magazines is between 200,000 and 250,000 lbs NEW for palletized ordnance and about 60,000 lbs of NEW for missiles.

Maximum Credible Event

The MCE is an inadvertent detonation of the entire quantity of Class 1, Division 1, high explosives stored in one cell. The MCE is assumed to occur during a handling operation when material is being stored or retrieved. For both the Type A and B HP magazines, the MCE is the rated safe storage capacity of any cell which is about 10,000 pounds of Class 1, Division 1, high explosives.

Material Handling System

The material handling system consists of one or more of the following equipment: overhead bridge crane, overhead bridge crane-monorail, railcart, sideloader, and frontloader. The final choice of material handling system will be the system that best accommodates the material packages; minimizes the number, types, and degree of hazards; requires the least number and skill level of operating personnel; and offers the lowest acquisition, operating, and maintenance costs.

The concept for material handling operations might be as follows. The bridge crane shown in Figure 2 travels the full length of the box structure. The bridge crane is designed to lift the heaviest container of missiles or pallet of ammunition in the inventory. The bridge crane lifts the package (container or pallet) and transfers it to an adjacent aisle. The package is then transported to the doorway by either the railcart, sideloader, frontloader, or bridge crane. In the case of the railcart, it is a flatbed cart with wheels which travel in a track located in each aisle. The track steers the cart along a safe path down the aisle and through the door opening to the exterior of the magazine. The other alternatives are to move the packages through the door opening to the exterior of the magazine with either a monorail or sideloader. Depending on the mode of transportation, the magazine would have a loading dock for ease in transferring packages from the magazine to railroad boxcars and flatbed trucks.

PREDICTED PERFORMANCE

Explosives Safety Quantity Distance

The following ESQD distance assume that the HP magazine has a rated safe storage capacity equivalent to 250,000 pounds NEW.

Inhabited Building Distance. The ESQD distance to inhabited buildings (IBD) is about 1,000 feet from the skin of the box (Type A and B) in all horizontal directions, as shown in Figure 6. The ESQD distance is dictated by the safe distance from debris and fragments-not from blast. As shown in Figure 6, the ESQD area for blast lies within the ESQD area for fragments and debris. The equivalent distance for a standard earth covered magazine storing 250,000 pounds NEW is:

$$ESQD = 50\ (MCE)^{1/3} = 50\ (250{,}000)^{1/3} = 3{,}150 \text{ feet}$$

Inter Magazine Distance. The ESQD distance for side-to-side and rear-to-rear spacing of an HP magazine is:

$$ESQD = 1.25\ (MCE)^{1/3} = 1.25\ (10{,}000)^{1/3} = 26.9 \text{ feet}$$

The equivalent ESQD distance for side-to-side and rear-to-rear spacing of a standard earth covered magazine storing 250,000 pounds NEW is:

$$ESQD = 1.25\ (MCE)^{1/3} = 1.25\ (250{,}000)^{1/3} = 78.7 \text{ feet}$$

The ESQD distance for front-to-rear spacing of an HP magazine is:

$$ESQD = 2\ (MCE)^{1/3} = 2\ (10{,}000)^{1/3} = 43 \text{ feet}$$

The equivalent ESQD distance for front-to-rear spacing of a standard earth covered magazine storing 250,000 pounds NEW is:

$$ESQD = 2\ (MCE)^{1/3} = 2\ (250{,}000)^{1/3} = 126 \text{ feet}$$

Summary. The table below summarizes the ESQD distances for a standard earth covered magazine and HP magazine. Both magazines store 250,000 pounds NEW. The MCE is 10,000 pound NEW for the HP magazine and 250,000 pounds NEW for the standard magazine.

Distance	ESQD Distance (ft) HP Mag	Std Mag
Inhabited buildings	1,000	3,150
Intermagazine side-to-side	26.9	78.7
Intermagazine front-to-rear	43.0	126.0
Intermagazine rear-to-rear	26.9	78.7

Encumbered Land

The HP magazine encumbers 83 acres of land to accommodate the magazine footprint plus the ESQD distance required for inhabited buildings. A standard earth covered magazine storing 250,000 pounds NEW encumbers 745 acres of land. Thus, the HP magazine reduces the encumbered land area by 88 percent.

Reduction in encumbered land = (745 - 83) 100% / 745 $\simeq$ 88%

Storage Density

The storage density is the NEW capacity of the magazine per acre of encumbered land based on inhabited building distance. The storage density for an HP magazine is:

Storage Density = 250,000/83 $\simeq$ 3000 lb NEW/acre

The storage density for a standard earth covered magazine is:

Storage Density = 250,000/745 $\simeq$ 336 lb NEW/acre

Thus, HP magazines will increase the munitions storage capacity of any fixed land area by:

Storage Density Increase = (3000 - 336)100% / 336 $\simeq$ 790 %

This means that 7 to 8 times more ordnance could be stored at existing storage sites by using HP magazines instead of standard earth covered magazines.

Noncompatible Storage

Current explosives safety regulations require noncompatible materials to be stored in different magazines. The high performance magazine offers the potential to safely store materials of different compatibility groups in the same magazine, provided noncompatible materials are segregated in different storage cells. This would significantly improve the productivity of storage operations and the utilization of storage space. This approach will not be safe for all compatibility groups, i.e. certain compatibility groups would have to be stored in different high performance magazines.

DEVELOPMENT

Technology

Development of the HP magazine concept requires operational requirements and design criteria for the box structure, storage cells, soil cover, and material handling system. The state-of-the-art and new technology needed to support development of these criteria are summarized below.

Box Structure. The technology base is sufficient to design the box structure to safely resist design dead loads from the soil cover, cell walls, storage contents, and material handling equipment. The technology base is not sufficient to accurately design the reinforced concrete roof (with soil cover) to limit the debris hazard nor to establish the exterior blast load environment (for safe pressure distance and blast loads on adjacent magazines).

Storage Cells. Design of the storage cells require definition of: (a) all possible mechanisms of sympathetic detonation, (b) the explosion environment inside the box structure due to the MCE in any cell, (c) the fragility of ordnance to each mechanism of sympathetic detonation, and (d) structural and architectural criteria for the cell walls to mitigate the MCE environment to safe levels in all acceptor cells (i.e., safe levels below the threshold for all mechanisms of sympathetic detonation and all types of munitions). The technology base for these factors is summarized below.

(a) Mechanisms of Sympathetic Detonation. Five mechanisms of sympathetic detonation are known. The mechanisms are blast overpressure, weapon fragment impact, debris impact, kinetic trauma, and thermal shock (cookoff). Additional mechanisms will be added if identified.

(b) MCE Environment Inside Box. Prediction methods for each mechanism of sympathetic detonation must be developed and verified. Empirical relationships are available to approximate the shock and gas pressures in the HP magazine. However, additional test data and computer programs (e.g. hydrocodes) must be utilized to develop better estimates of the extreme shock and gas pressure-time history and temperature-time history. The critical mass/velocity of weapon fragments can be obtained for many ordnance from the existing data base and safely estimated for most other ordnance. However, methods must be developed (using finite element and finite difference methods) and verified (by test) to predict the wall debris impact and kinetic trauma loading on the acceptor.

(c) Munition Fragility. The technology base is not adequate to predict the threshold level for sympathetic detonation of all possible acceptor munitions due to the known mechanisms of sympathetic detonation. Further, there are too many combinations of the critical fragility parameters, such as explosive composition, critical charge diameter, and casing thickness, to establish the threshold level for all munitions in the inventory. Ordnance with similar characteristics will be grouped and safe fragility levels (using both test and analysis) will be established for each group. Ordnance with extraordinary load output or fragility may be excluded from the HP magazine. A mix of ordnance, representing the worst case loads and fragilities of all munitions in the inventory, will be used as the donors and acceptors in tests.

(d) Non-Propogation Cell Walls. The technology base is not sufficient to design the cell wall to prevent sympathetic detonation. Technology exists to design barriers for relatively small MCEs and large standoff distances (less than about 2,000 lb NEW at more than about 4 feet standoff distance). Essentially no technology exists to design a barrier for the MCE associated with an HP magazine (10,000 lb NEW with 2 feet minimum of air space between the explosive charge and cell wall). Concepts must be developed to mitigate the environment at the acceptor to below threshold levels for sympathetic detonation. Analytical methods (using FEM and FDM programs) must be developed to predict the response of the walls and the effect of the walls on the mechanisms of sympathetic detonation. Scale model and full scale tests will be used to help develop and to verify the analytical prediction methods.

Roof/Soil Cover. Design of the roof and soil cover requires definition of: (a) the blast environment outside an HP magazine, (b) the fragment and debris environments outside an HP magazine, and (c) the safety thresholds for pressures, fragments, and debris outside the magazine. The technology base for these factors is described below.

(a) <u>External Blast Environment</u>. There are test data on the blast environment outside tunnel magazines, based on explosive tests of small and large scale tunnel magazines. Theory based on these data are probably adequate to predict the blast environment outside an HP magazine in which the soil cover depth is sufficient to force most of the blast overpressures to vent through the access openings in the box structure before the roof is breached by the MCE.

(b) <u>Fragment and Debris Environments</u>. Some test data and incomplete theory are available to predict the shock and gas loads inside the box structure, and the resulting mass, launch velocity, trajectory, and strike range of debris from partially vented explosions inside earth-covered boxes. However, the theory is based on small scale tests involving 0.5 to 10 pounds NEW detonated inside partially vented earth-covered boxes. More technology is needed to develop a prediction model to characterize the reinforced concrete roof failure, the effective volume of soil in the breached area, and the key fragment and debris parameters (launch velocity, launch angle, size, drag area, and drag coefficient). The probability density functions for these fragment and debris parameters will then be used in a probabilistic trajectory program to predict the debris density vs. range.

(c) <u>Safety Thresholds</u>. The safe pressure, fragment, and debris limits will be those stated and implied in current explosives safety regulations .

Material Handling System. The technology base is sufficient to support development of the material handling system. However, considerable study is needed to identify the best system to minimize the hazards, the number and skill level of manpower, and the acquisition, operating, and maintenance costs.

Development Plan

End Product. Standard designs (construction drawings and specifications) for the HP Magazine.

Major Milestones. The major milestones for research and development of the HP magazine are:

Milestone	89	90	91	92	93	94	95	96	97
	Fiscal Year								
A. Concept Feasibility	—	—	—						
B. Demonstration Tests				—	—	—			
C. Prototype Development & Certification						—	—	—	
D. Standard Design							—	—	—

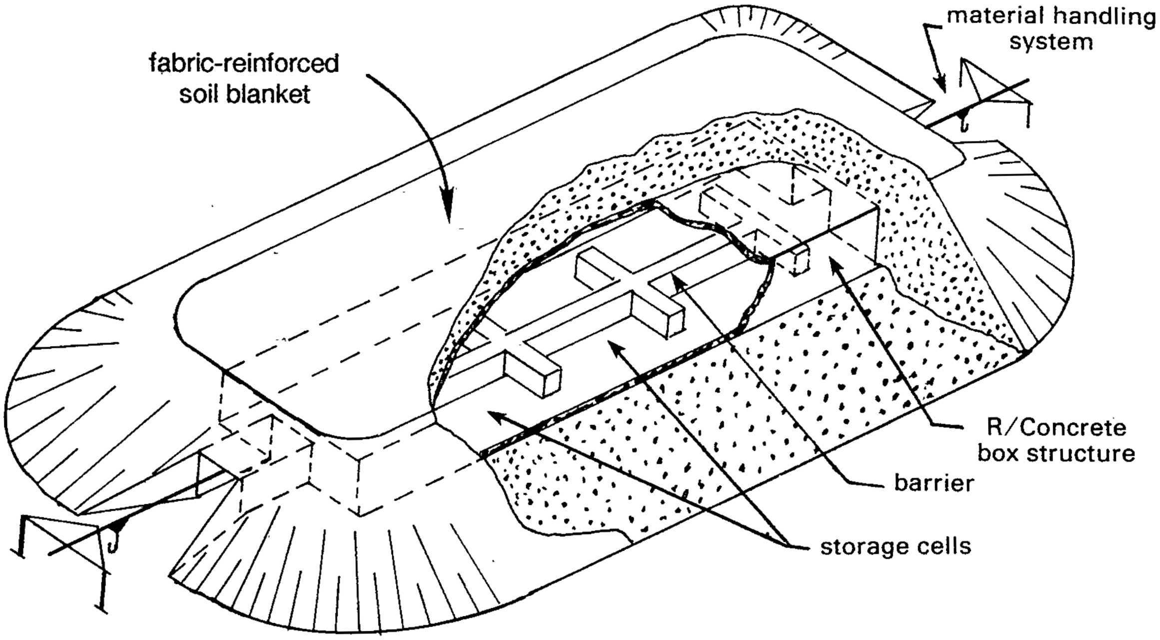


Figure 1. High performance magazine.

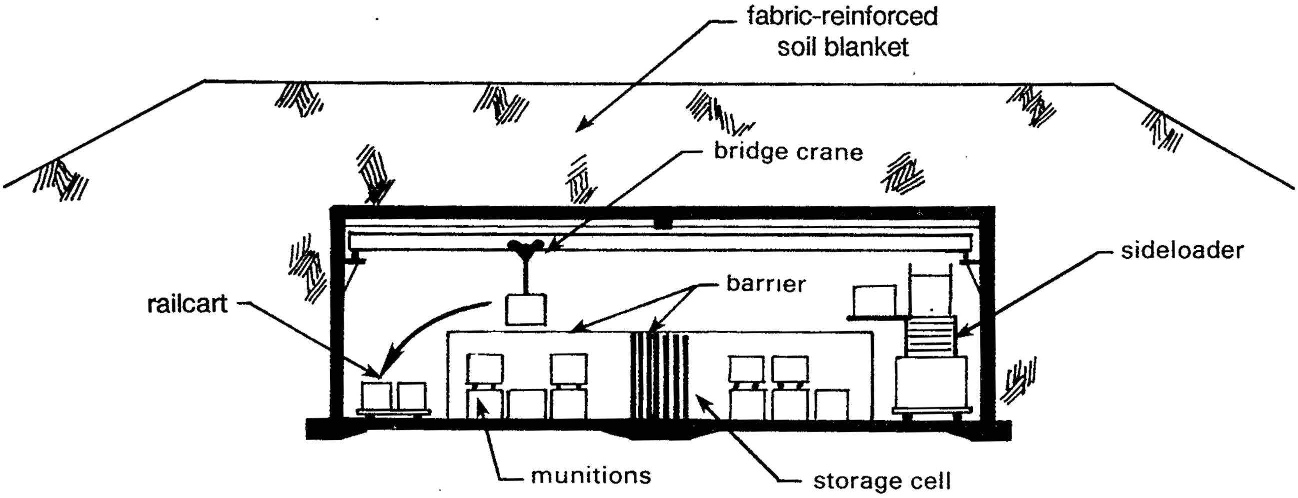
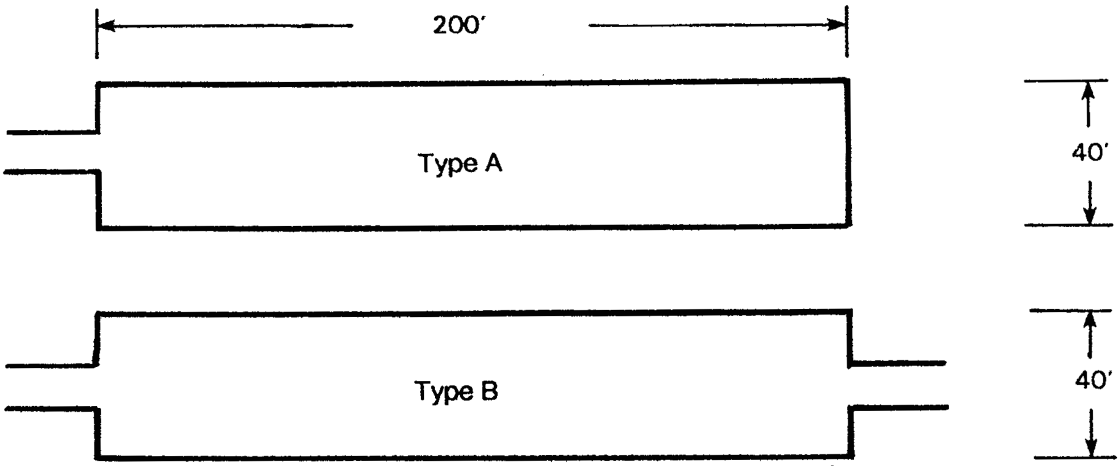
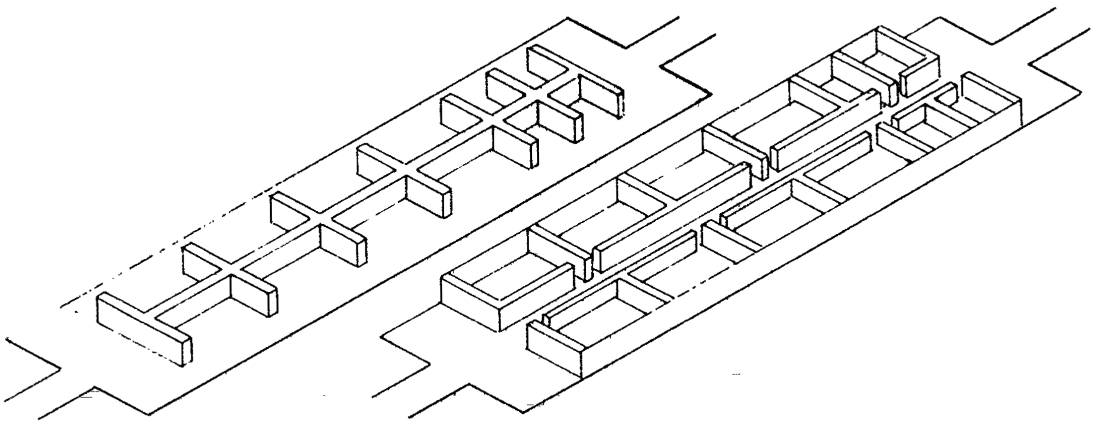


Figure 2. Section view of HP magazine.



Type	Box L x W x H (ft)	Door W x H (ft)	Door No.
A	200 x 40 x 15	12 x 11	1
B	200 x 40 x 15	12 x 11	2

Figure 3. Alternative floor plans for HP magazine.



(a) Two-aisle concept.

(b) One-aisle concept.

Figure 4. Alternative arrangements for storage cells and aisles.

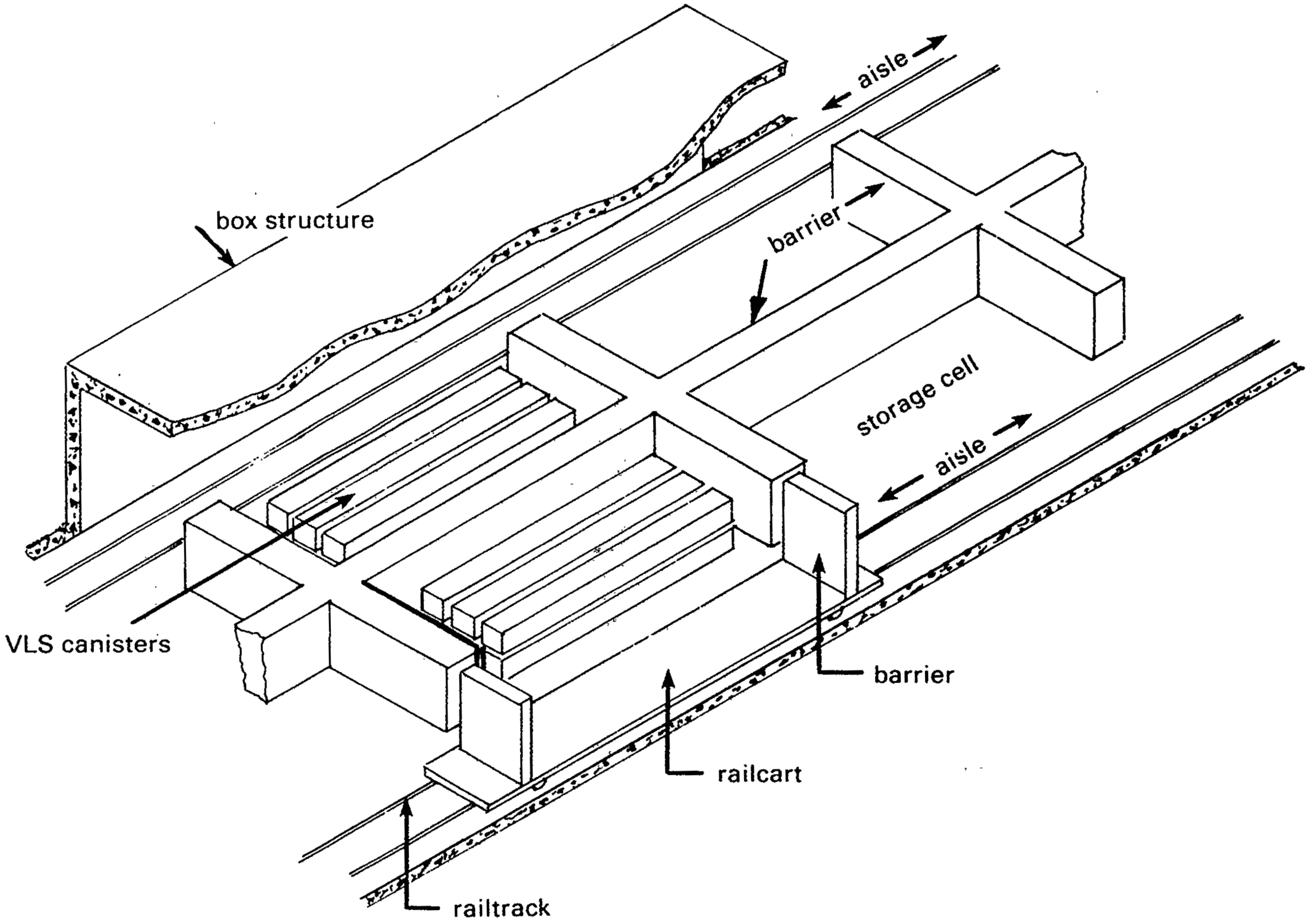


Figure 5a. Storage configuration for surface-launched missiles.

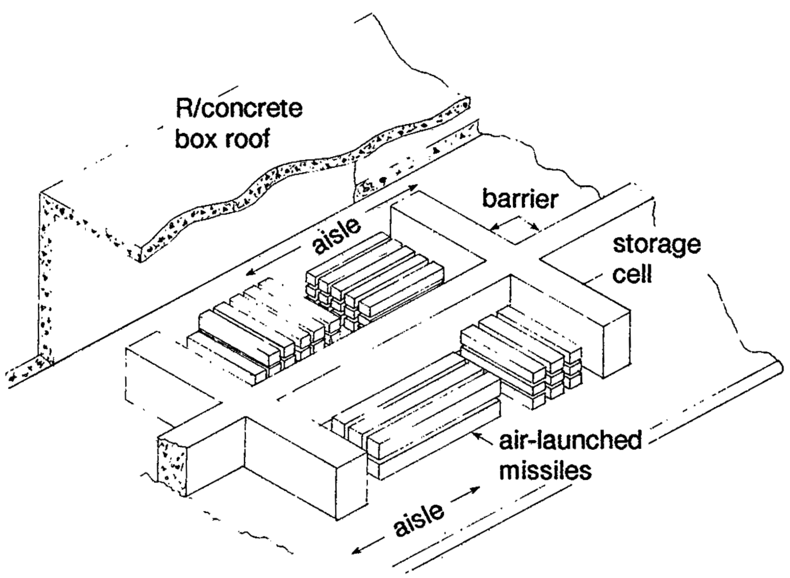


Figure 5b. Storage configuration for air-launched missiles.

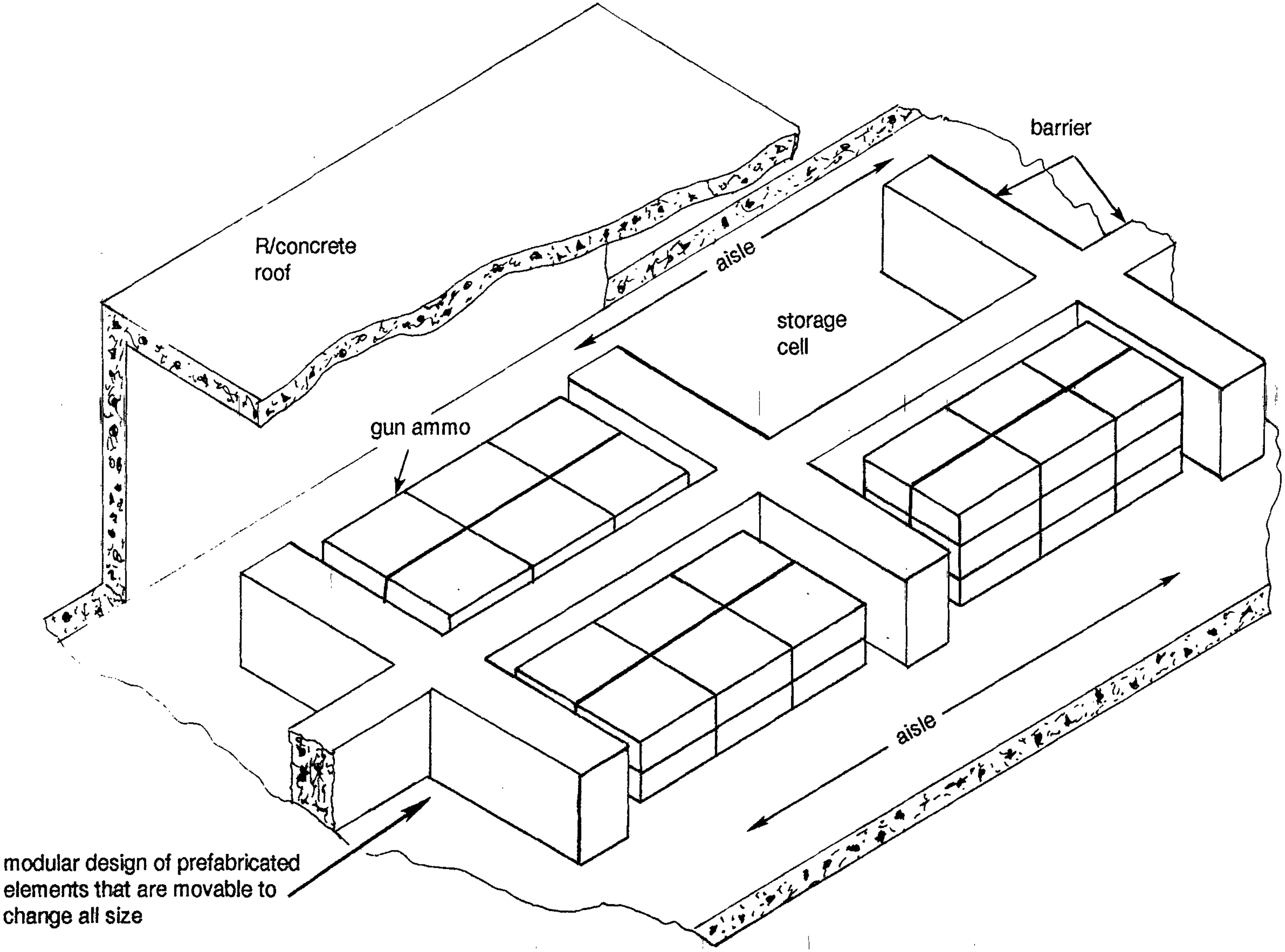
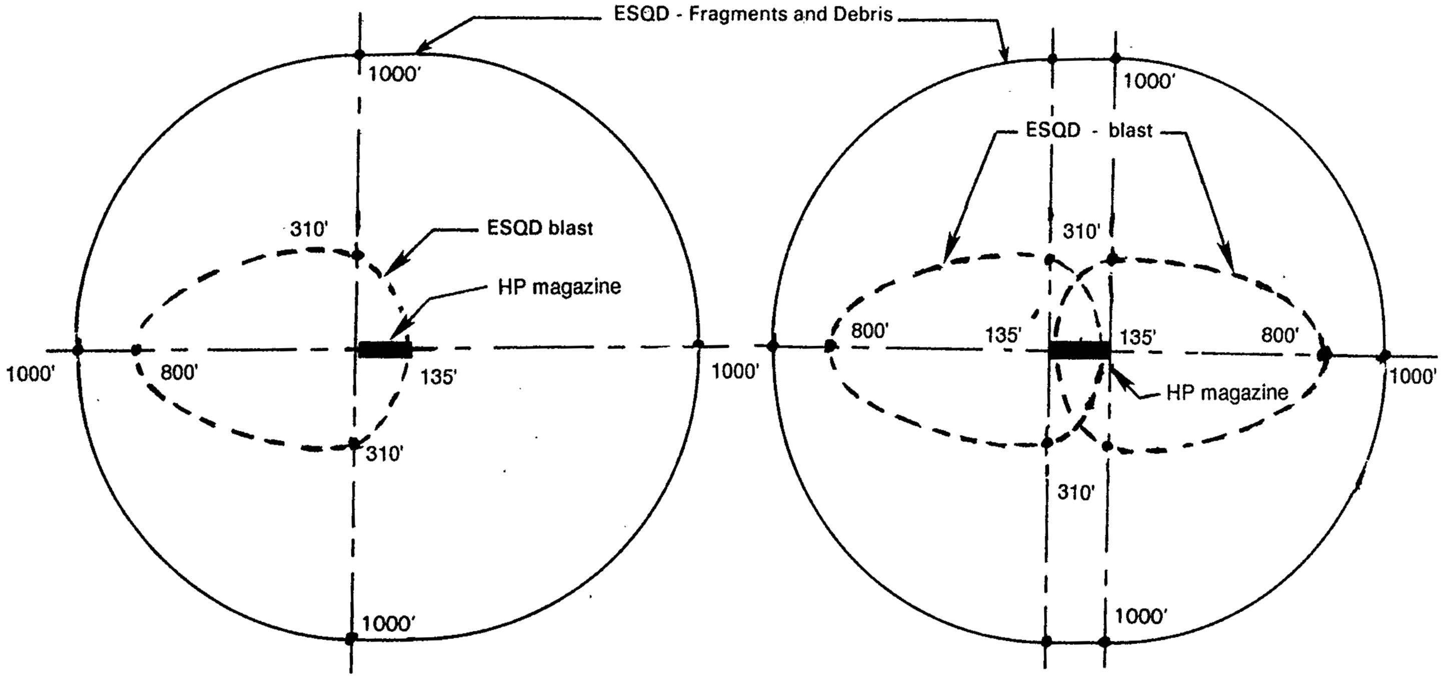


Figure 5C. Storage configuration of palletized munitions.



Type A-HP Magazine

Type B-HP Magazine

Figure 6 . Predicted explosives safety quantity distance (ESQD) arcs to inhabited buildings from an HP magazine storing Class1, Division 1, high explosives.